Thorax tissues segmentation: a first step for a dynamic beating heart digital phantom

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Abstract *- **In this paper, we present an approach to obtain a beating heart digital phantom. The goal of this phantom is to obtain a dynamic model of the beating heart surrounded with its neighbor closest tissues and organs. In this phantom, thirteen different tissues were segmented from a dynamic sequence of 20 thoracic CT volumes. We use a semi-automatic method to describe this tissues of the first volume. The temporal evolution of these tissues has then been estimated by propagating this first segmentation to the others volumes by an elastic registration. This dynamic digital phantom can now be used to simulate a therapy, to model the cardiac electrical field, to evaluate registrations methods.***

Index Terms *- **Image Processing, Simulation.***

I. INTRODUCTION

More and more procedures use now digital phantoms complementary to real data experiences. These phantoms can be build from scratch or obtained from a real case. The advantage of real anatomy-based digital phantoms is to propose a model and a ground truth with a realistic shape complexity. When dealing with cardiac images such a phantom should also provide the dynamic information of the anatomical deformations during the heartbeat. The goal of this paper is to describe the methodology used to provide a digital phantom of the heart structures and the surrounding tissues. More precisely our digital phantom should include the anatomy and the temporal deformations of the several following heart and thoracic structures: right ventricle with a portion of the pulmonary artery (*RV-PA*), left ventricle (*LV*), right atrium with a portion of superior and inferior vena cava (*RA-CVA*), left atrium with pulmonary veins (*LA-PVs*), aorta (*Ao*), myocardium (*Myo*), right lung (*RL*), left lung (*LL*), bronchi (*Br*), spine (*Sp*), external thorax (*ET*), medium thorax (*MT*), internal thorax (*IT*).
Multi-slice CT scanner can provide heart images during the cardiac cycle with a high spatial and temporal resolution. Our idea is to segment the several thoracic tissues on one sequence of a dynamic CT in order to create a digital phantom. Some methods have been proposed for the segmentation of individual organs of the thorax like *LV*, *Ao*, *LA*, Lungs or the whole heart. However, to our knowledge no automatic procedure exists to segment together the several heart structures and the surrounding organs needed to construct a phantom.

II. MATERIALS AND METHODS

The phantom construction is based on a 4D CT sequence of a healthy heart. The sequence is composed by 20 volumes acquired at each 5% of the cardiac cycle. Each volume contains $512 \times 512 \times 295$ isotropic voxels with a spacing of 0.3125 mm. The images cover the thorax from the superior vena cava to the diaphragm including the whole heart.
The digital phantom is obtained by the segmentation of the different anatomical structures on all the volumes of the sequence. This segmentation is decomposed into 2 steps: (1) A first static semi-automatic segmentation (S_1) of thirteen different tissues of the thorax on the first volume (V_1) of the sequence. (2) An intensity-based elastic registration between V_1 and the others volumes of the sequence (V_i) $(i = 2, 3, \cdots, 20)$, to obtain a deformation field T_{1-i} for each volume. These deformation fields T_{1-i} are then used to propagate the first tissue segmentation S_1 to the other volumes of the sequence.

II.1. Static semi-automatic segmentation

The following 3D active-contours approach is used to obtain the segmentation of each of the thirteen different organs and tissues presents in the first volume of the sequence: 1) A region of interest (ROI) is manually selected around the organ or tissue to segment. 2) The selected ROI is preprocessed by a manually selected threshold mapping function. 3) An initial shape is manually inserted inside the foreground region. 4) The active contours algorithm is then performed. 5) The evolution of the active contour is manually stopped when it reaches the desired approximation. 6) If necessary, the regions with poor boundary information are corrected manually (e.g. between *LA* and *LV*).
This approach has been applied directly to the *RV*, *LV*, *Ao*, *LA*, *LL*, *RL*, *Br* and *ET* because they have homogeneous intensities and high contrast. However, some specific processes were added for the segmentation of *RA-CV*, *Myo*, *Sp*, *MT* and *IT*. As an example, for *Myo*, its external shape was found using active contours initialized by the union of the previously segmented *RV*, *LV*, *RA*, *LA* and *Ao*. The final *Myo* shape is given by subtracting *RV*, *LV*, *RA*, *LA* and *Ao* from this estimated external shape.

II.2. **Dynamic single-atlas-based segmentation**

The results of the static semi-automatic segmentation are used as an atlas for the segmentation of the others volumes of the dynamic sequence. Intensity-based registration is performed between the first volume and the others. The obtained deformation fields are used to deform the static semi-automatic segmentation of the first volume.
The registration approach has two stages: an affine global registration followed by an elastic registration. The affine registration transformation matrix is estimated by minimizing the Sum of Squared Difference metric between the volumes to register. This affine transformation matrix is used to initialize the elastic registration stage. The elastic registration is performed by minimizing the Mutual Information metric between the volumes. This choice of similarity measures stems from a previous study on segmentation of *LA-PV*s [1]. This registration has been performed using the Elastix software [2].

III. **RESULTS**

Results of the static semi-automatic segmentation of several structures of this first volume of the sequence are presented in Fig. 1.

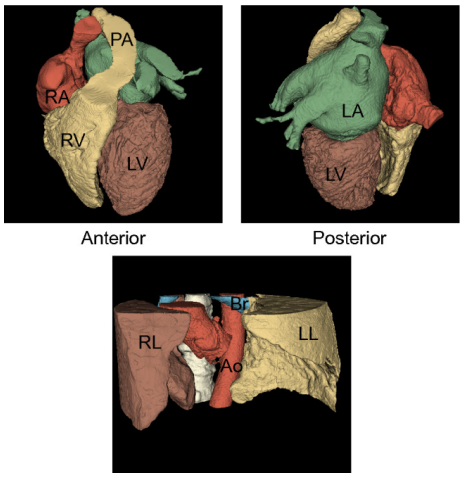

Figure 1: Segmentation results. Top: Anterior and posterior view of *RV-PA*, *LV*, *RA-CV* and *LA-PV*s. Bottom: *Ao*, *RL*, *LL*, *Sp* and *Br*.

The effect of the propagation of the first initial semi-automatic segmentation to the others volumes of the sequence can be seen on Fig. 2 which shows the dynamic of *LA-PV*s during the cardiac cycle. The shape propagation from the static semi-automatic segmentation (0 %) to the other time steps of the cardiac cycle can be clearly seen especially the filling evolution of the *LA* can be followed over the cycle.
The final digital phantom is available as a sequence of labeled voxels volumes or as labeled 3D surface shapes. One other interesting result of this segmentation process is that we have the displacement vectors of all the voxels during

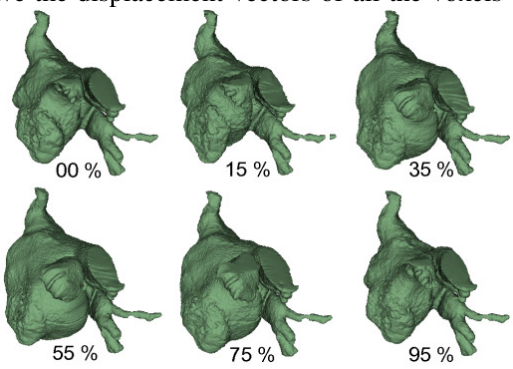

Figure 2: Shape evolution of the *LA-PVs* during the cardiac cycle.

the cardiac cycles. This information can be interesting for the simulation of the therapy or for the modeling of the electrical cardiac field.

IV. **CONCLUSION**

A dynamic digital phantom of the beating heart surrounded by its neighbor closest tissues and organs is built from a high resolution CT sequence. A semi-automatic segmentation is used to obtain a single-atlas volume at the 0% time steps of the cardiac cycle. Then, a single-atlas-based segmentation approach is used to obtain the anatomical shapes in the others volumes of the sequence. At the end, the digital phantom contains the dynamic of thirteen different tissues and organs taken at each 5% of the cardiac cycle.

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